NSF Nanoscale Science and Engineering Grantees Conference, Dec 16-18, 2003
Grant # : 0210533

# NIRT: Nanoscale Magnetic Microscopy with Multi-Photon Absorption Polymers and Y-Junction Nanotubes

*NSF NIRT Grant 0210533*
PIs: **Michael J. Naughton, John T. Fourkas, Kris Kempa**
Boston College

The aim of this project is to develop a set of nanoscale microscopy tools, in particular for magnetic force and force resonance microscopies, that have the capability of providing significantly enhanced spatial and spin moment resolution over extant instruments. Four related approaches are being pursued in parallel:

1. Branched nanotubes, nanowires and nanopolymers as piezoresistive cantilever sensors,
2. Multi-photon polymerization-fabricated cantilevers as fiber-optic waveguides,
3. Straight carbon nanotubes and $ZnO_2$ nanowires as RF antennas,
4. GMR-based non-mechanical spin imaging using MPP probes.

The first year of this project was devoted to preparation and characterization of the nanoscale probes, including carbon, zinc oxide and polymeric probes in cantilevered geometries, and to purchasing and setting up of required equipment, including an AFM having extensive nonmagnetic components as well as conducting AFM capability. These cantilevers, whose typical dimensions are 30 nm diameter by 1 μm long, will have a nanoparticle magnet attached to the free end. In an applied magnetic field, this small magnet serves to distort the local field near itself, generating an inhomogenous or gradient field. This gradient acts to supply a magnetic force on magnetic spins in a nearby material (the subject under study), causing the cantilever to bend. The bending of the branched, "divining rod" device is detected either electrically (nanotubes, nanowires, or polymers) or optically (polymers). Since the size and mass of the sensing device are intrinsically small, very small forces can be detected, meaning very small numbers of specimen spins can be resolved, as the sample surface is scanned with the cantilever. This nanoscale magnetic microscope (nMFM) will be further refined to a nanoscale magnetic resonance force microscope (nMRFM) by using a high frequency electromagnetic field to drive a small volume of the specimen spins into magnetic resonance.

Using branched nanotubes and nanowires, mainly carbon- and zinc-oxide-based, respectively, and polymeric fibers fabricated by two-photon polymerization, we hope to avoid the current spatial resolution limitations on magnetic scanned probe microscopy imposed by the use of conventional optical (reflective and interferometric) detection. Our sensing devices are intrinsically nanoscale in dimension (10 to 30 nm diameter cantilevers, for example, see Figures 1 and 2 below), with a few different geometries and detection schemes being pursued.

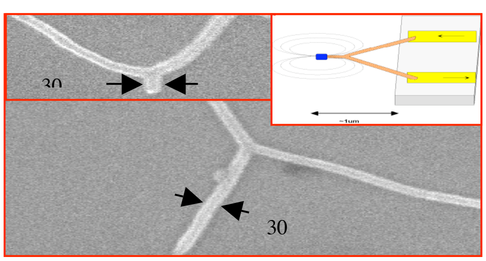



**Fig. 1** Branched carbon nanotubes produced at Boston College for use as cantilevers for nanoscale magnetic microscopy. Left inset shows schematic of piezoresistive sensing scheme.

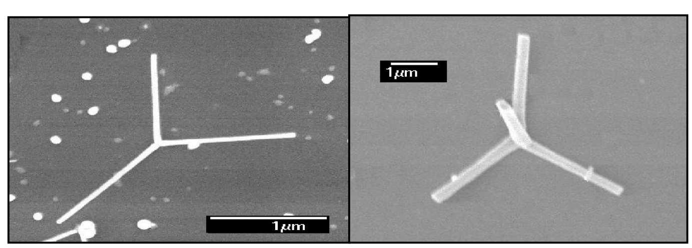
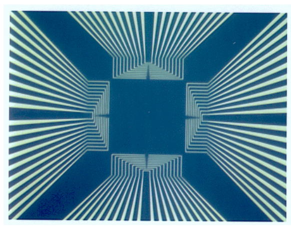



**Fig. 2** Examples of branched $ZnO_2$ nanowires produced at Boston College for use as nanoscale probes. Image on the right shows self-supported tetrahedral structure that will be tested for gated nonlinear piezoconductance.

In this first year of the program, we have worked to improve the synthesis process for V- and Y-branched carbon nanotubes and nanofibers, in collaboration with colleagues in Z. Ren's lab at Boston College. We have also extended the branched probe studies into semiconductor nanowires, and have begun synthesizing $ZnO_2$ wires of various morphologies. We are now preparing substrates for electrical and piezoelectrical characterization of these materials, including with the aid of a recently-purchased conducting AFM probe for the Veeco AFM that is dedicated to this NIRT. Contact to the nanoscale products will be made in two approaches: leads on devices, and devices on leads. The former will be achieved via e-beam and FIB lithography on substrates containing nanodevices, while the latter with the aid of SPM manipulation of nanodevices on previously-prepared nanoelectrodes [2], such as those shown in Figure 3 below.



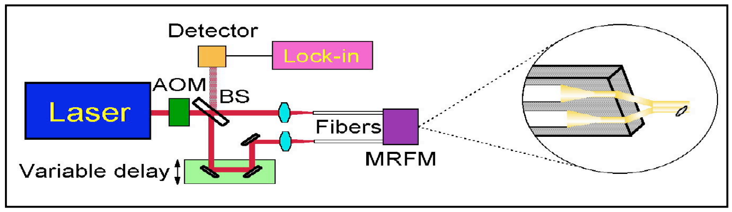



**Fig. 3** Au leads on Si chip with various separation gaps for testing electrical properties of branched cantilevers.

**Fig. 4** Schematic of the optical dual-pronged cantilever scheme with an antiresonant ring for detection. AOM = acousto-optic modulator, BS = beam splitter.

In addition to these nanotube and nanowire approaches, we are investigating sensing schemes using cantilevers and rigid probes made of polymer, fabricated using multiphoton polymerization (MPP). This technique allows one to make microscale devices of arbitrary shape and form with close to nanoscale precision (<200 nm feature size) [3,4,5]. We have recently characterized the mechanical, thermal and dielectric properties of a series of microscale MPP-fabricated polymer cantilevers, made for this project in our labs at Boston College [6,7]. Possible nanoscale sensing with these polymer microdevices will be investigated both electrically and optically. That is, we are now able to photodeposit metals onto the surface of the polymer, and are working on attaining control over the connectivity of the metallic nanoparticles thus the (strain-dependent) conductivity of the coating. For optical sensing, an antiresonant ring interferometer with a frequency- and amplitude-stabilized single-mode laser will be used to enhance detection sensitivity, a schematic for which is shown in Figure 4. Figure 5 shows examples of microscale polymer cantilevers fabricated with the MPP technique, as well as demonstrates our ability to fabricate 3-D polymeric objects on a variety of substrates, including directly onto the end of an optical fiber. A near-future step is to fabricate branched polymer cantilevers bridging a pair of such fibers.

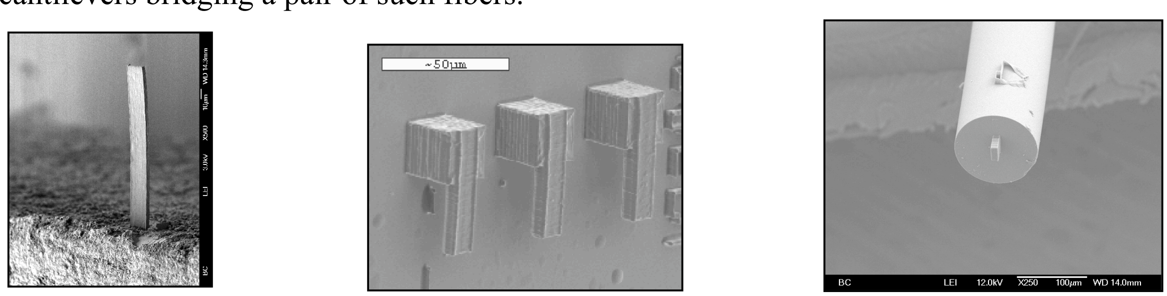


**Fig. 5** (left and center) Microscale polymer cantilevers fabricated with a laser by the MPP method, which presently has a feature size limit of about 200 nm, anticipated to soon reach below 70 nm.
(right) Example of our ability to fabricate 3-D polymer optical waveguide components directly onto the end of an optical fiber, here 125 μm in diameter.

**References**

[1] For further information about this project email **<naughton@bc.edu>**
[2] J. Moser, R. Panepucci, Z.P. Huang, W. Li, Z.F. Ren, A. Usheva and M.J. Naughton, J. Vac. Sci. Tech. B 21, 1004 (2003).
[3] T. Baldacchinni, *et alia*, SPIE Proc. 4633, 136 (2002).
[4] T. Baldacchini, R.A. Farrer, J. Moser, J.T. Fourkas, M.J. Naughton, Synthetic Metals 135-136, 11 (2003).
[5] T. Baldacchini, C. LaFratta, R.A. Farrer, M.C. Teich, B.E.A. Saleh, M.J. Naughton, J.T. Fourkas, submitted to Nature Materials.
[6] Z. Bayindir, C. LaFratta, T. Baldacchini, J.T. Fourkas and M.J. Naughton, submitted to Applied Physics Letters.
[7] C. LaFratta, T. Baldacchini, R.A. Farrer, M.C. Teich, B.E.A. Saleh, M.J. Naughton, J.T. Fourkas, submitted to Journal of Applied Physics.